This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

**Usage guidelines**

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

**About Google Book Search**

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

HARVARD UNIVERSITY.

LIBRARY

OF THE

MUSEUM OF COMPARATIVE ZOÖLOGY

42,834

Bequest of

WILLIAM McM. WOODWORTH.

July 6, 1915

JUL
42,834
-W

ON THE

# PHYSICAL BASIS OF ANIMAL PHOSPHORESCENCE

BY

S. WATASÉ

Reprinted from Biological Lectures delivered at Wood's Holl, 1895

BOSTON
GINN & COMPANY
The Athenæum Press
1896

Sm

JUL 6

# SEVENTH LECTURE.

## ON THE PHYSICAL BASIS OF ANIMAL PHOSPHORESCENCE.[1]

S. WATASÉ.

WHATEVER view we may take as to the nature of vitality, it is evident that we can know life only through the physical, chemical, or mechanical manifestations, which an organism displays at various phases of its existence. Our organs of sense, which supply directly or indirectly the material of human knowledge of both the animate and inanimate world, are only related to force, or are set into a state of excitation by motion of certain kinds, which we call a stimulus. Whatever view, therefore, a biological philosophy may lead us to accept in regard to the ultimate nature of life, our primary step in the study of vitality must begin with the examination of its material manifestations.

Among many physical phenomena manifested by the living organism there are few so striking, and none appear so isolated, as the phenomena of the emission of light. Thus, Darwin, in his discussion of some special difficulties of the theory of natural selection, says: "The luminous organs which occur in a few insects, belonging to widely different families, and which are situated in different parts of the body, offer, under our present state of ignorance, a difficulty almost exactly parallel with that of the electric organs," and "it is impossible to conceive by what steps these wondrous organs have been produced."[2]

---

[1] The present paper is part of three lectures on Animal Phosphorescence, delivered at the Marine Biological Laboratory at Woods Holl, during the summers of 1894 and 1895, and elsewhere. A monographic account of the subject, with a full bibliography, will be presented in the near future.

[2] Darwin: Origin of Species.

But viewed from the standpoint of cell physiology, the phenomena of animal phosphorescence is the result of physico-chemical changes in the living protoplasm, probably of the same nature as that of heat production, the only peculiarity of the former being that it manifests itself in such a form as to affect the most potent of our special senses, — the sense of sight, — and the latter, the sense of temperature.

On *a priori* ground it is easily conceivable that the animal that produces heat, as all animals can, may just as well produce light under certain circumstances, for both are but the manifestations of the same energy, and can be produced by essentially the same physico-chemical antecedents.

The production of light by the living organism becomes still more interesting, and appears unique when we remember that the light thus produced is not accompanied by any sensible heat.

> "You gaudy glow-worms, carrying seeming fire,
> Yet have no heat within ye!"[1]

This difference between the light produced by the activity of the living organism and by the purely artificial process has also been pointed out by the natural philosopher, Robert Boyle. In one[2] of his several contributions on the subject he says: "That whereas a coal, as it burns, sends forth store of smoke or exhalations, luminous wood does not so"; and "that whereas a coal in shining wastes itself at a great rate, shining wood does not"; and "that a quick coal is actually and vehemently hot, whereas I have not observed shining wood to be so much as sensibly lukewarm."[3]

The same peculiarity in the light of the living substance has been recognized by Faraday, Matteucci, Young, Langley, and Very, and by the last two it has been made the subject of a beautiful research within recent years.

---

[1] Fletcher: The Elder Brother, act iv, sc. 1, 1637.

[2] R. Boyle: Observations and Trials about the Resemblances and Differences between a Burning Coal and Shining Wood, *Phil. Trans.*, No. XXXII, 605, 1667–1668.

[3] It is hardly necessary to say that Boyle was not aware of the fact that the luminosity of the shining wood is caused by the activity of the living organism.

Readers of the *Life of Faraday* will notice what a lively interest he took in the luminous phenomena of the fire-fly and the glow-worm. The journal[1] he kept during his travel over the continent with Sir Humphry Davy in 1814, when Faraday was twenty-two years old, makes frequent mention of his experiments with the luminous phenomena of the fire-fly and the glow-worm. I quote him at length because he correctly surmised all the results of his later workers, and also because his unassuming but remarkable record of his observations has escaped the notice of writers on animal phosphorescence subsequent to the publication of Faraday's Life. (Italics are mine.)

"On the way home many fire-flies appeared, emitting their transient light.[2] I caught several; and on arriving at the house *endeavored to ascertain whether the luminous appearance depended on the life of the fly*. I found one apparently dead; and separating the part which emitted light from the rest of the body, it appeared filled with a white glutinous matter, which, when extended and exposed to the air, shone for about a minute.

"I killed a fly suddenly, and separated the matter. It was shining at the moment I killed it; but when dead it ceased to shine. On separating the part and exposing it to the air it immediately shone brightly as when attached to the fly, and over the whole surface, although only the section was exposed to the air. It at length became dim; but on compressing it, and exposing a fresh part to the air, it shone brightly as at first, and thus it continued luminous for above forty minutes. At last it became totally extinct; and the same effect took place with other flies treated in the same manner. *It is probable, from the intermitting and regular appearance of the light, that it has a dependence on the respiration; and at least it is evident that air is sufficient to cause this matter (probably a secretion) to shine. No heat was sensible to the hands or to the underlip (the most delicate part of the body).*"

---

[1] Dr. Bence Jones: Life and Letters of Faraday, Vol. I, 1870, pp. 90, 91, 125, 141, 142, 144–146.

[2] Friday, June 3, 1814 (Terni), Italy, pp. 141, 142.

In his entry "Sunday, July 10, 1814, Geneva," Faraday describes his experiments on glow-worms.

"This evening many glow-worms appeared, and of four which I had put in a tumbler with green leaves, two shone very brightly. I separated the luminous part of one in full vigor from the body. It soon faded, and in about ten minutes ceased to emit light; but on *pressing it with a knife, so as to force the matter out of the skin, it again became luminous, and continued to shine for two hours brightly*. One I found on the floor crushed unawares by the foot. I separated the luminous part of this insect, and left it on paper. It shone with undiminished luster the whole evening, and appeared not at all to have suffered in its power of emitting light by the mixture and confusion of its parts, *so that it appears to depend more upon the chemical nature of the substance than upon the vital powers of the animal; but at the same time, it appears, from the variations in splendor, accompanied by motions in the living animal, that it may be much influenced or modified by, or in some manner submitted to, the powers of the worm.*

"The matter which appears to fill the hinder part of the body in the shining season is yellowish-white, soft, and glutinous. It is insoluble, apparently, in water or in alcohol. It does not immediately lose its power of shining in water. Heat forces out a bright glow, and then it becomes extinct; but if not carried too far, the addition of moisture after a time revives its power. No motion or mixture seems to destroy its power whilst it remains fresh and moist, but yet a portion thus rubbed sooner lost its light than a portion left untouched. The time of its continuance in a luminous state was very various, and perhaps depends upon the state of the worms from which it was taken. The death of the worm seemed to have no immediate effect upon the illumination of the hinder part; and with respect to the length of time that it continued to shine afterwards, it seemed indifferent whether it was left on the body or taken off; but when extinct, exposure of the interior to air always caused a fresh emanation of light. I found a worm which emitted light from a very small part of the body, and very feebly, and for a very short time together. The worm was larger than the ordinary species, and had more divisions. The power of emitting light in the ordinary worm seemed proportionate to the age of the animal."

*Monday, 11th.* "The matter of the worms referred to yesterday still shines. It was detached from the animal at 8.24, and still promises to emit light much longer."

*Tuesday, 12th.* "The matter was luminous this day at 10.41, though faintly, and at twelve o'clock no light could be perceived. The matter had become quite dry and semi-transparent, but the addition of water produced no particular effect."

Faraday's results may be briefly stated as follows: —

(1) There is a chemical substance in the glow-worm and the fire-fly which has power to shine independently of the life of the insect.

(2) This substance is probably a secretion of the insect.

(3) The shining depends on the respiration, and the air is enough to cause this substance to shine.

(4) From the variation in the splendor of light, accompanied by motions in the living animal, the animal, as a whole, has in some way the control of the external manifestation of light.

Matteucci, also, in his letter to Duma,[1] and elsewhere,[2] came to the same conclusion as Faraday, and says: "In the glow-worm there is a substance which, without any sensible heat, diffuses a light that does not require the integrity of the animal and of its living state in order to manifest itself with its peculiar properties."

It will contribute to the clearness of the whole, if, instead of examining various other theories proposed from time to time, on the nature of animal light, I dwell briefly here on the relation of objective and subjective aspects of what we call the sensation of light and of heat, or the relation of various kinds of ether vibrations to the specific energy of senses.

We habitually associate the sensation of light with that of heat, so that it becomes almost impossible to separate them in our common experience; and when we meet with such a phenomenon as the production of light from the animal tissue without any sensible heat, it appears as if it were a totally isolated physiological phenomenon with no parallel in the ordinary activity of life.

---

[1] Carlo Matteucci: Sur la phosphorescence du Lampyre d'Italie (L. Italica). *Compt. Rend.* XVII, p. 309, August 14, 1843.

[2] Matteucci: Lectures on the Physical Phenomena of Living Beings, 1848, p. 165.

According to the physicist, however, the external agent which gives rise to the sensation of light in our organism is not much different from that which gives rise to the sensation of heat. Heat and light are only the variations of the same radiant energy. There is an absolute continuity in the nature of the two phenomena — the vibrations of ether.

"When the wave-length is greater than 812 millionths of a millimeter no luminous effect is produced on the eye, though the effect on the thermometer may be very great. When the wave-length is 650 millionths of a millimeter the ray is visible as a red light, and a considerable heating effect is observed. But when the wave-length is 500 millionths of a millimeter, the ray, which is seen as a brilliant green, has much less heating effect than the dark or the red rays, and it is difficult to obtain strong thermal effects with rays of smaller wave-lengths, even when concentrated."[1]

The light and heat are so very different to us because we perceive them with different organs of sense. The heat radiation, or the waves of ether which have most *heating effect*, we perceive with the organ of temperature sense, while a similar radiation, with different wave-lengths, which have most *luminous effect*, we perceive with the organ of sight.

The difference between heat and light, therefore, "is purely subjective, depending on our organization and not on the nature of external objects."[2] There is an absolute continuity in the nature of external disturbances which create in us the sensations of heat and of light, the difference between them being that of degree and not of kind. Expressed, therefore, in terms of visual sensation, heat is invisible light; and light, expressed in that of temperature sense, is heat with a very little heating effect.

---

[1] Clerk-Maxwell: Theory of Heat, Chap. XVI., On Radiation, p. 239.

[2] Stokes: On Light, p. 266.

If our organs concerned in the sensation of light were somewhat different from what they are now, it is possible that what appears as luminous may have no such effect, and what appears as dark may even appear as luminous. "It is quite conceivable that animals might exist to which obscure heat rays might be visible, and to which man and mammals generally would appear constantly luminous."[1]

The animal organism is an actual apparatus of combustion, in which carbon compounds are constantly burnt, and from which carbonic acid is always escaping. There is no difficulty in conceiving that organisms which produce heat in this way may under certain circumstances produce light, if the combustion of the material in the body could be carried on in such a manner as to impart a more rapid vibration to the surrounding ether than that which results in the production of thermal radiation.

The vibration of ether thus produced with higher frequency and of shorter wave-lengths, such as we see in the fire-fly, would affect the organ of vision, but not the organ of temperature. *And this difference of result, so conspicuous to us, may not imply more than a very slight variation on the part of the individual organism at the start.* Nature desires, if I may use such an expression, nothing but light in such an organism as the fire-fly, and produces this with the least possible waste.

That this is a legitimate inference may be shown from the several works of physicists. Several years ago Professor Young[2] examined the spectrum of the fire-fly and stated his important observations in the following form.

"The spectrum given by the light of the commom fire-fly of New Hampshire (*Photinus ?*) is perfectly continuous, without trace of lines either bright or dark. It extends from a little above Fraunhofer's line *C* in the scarlet to about *F* in the blue, gradually fading at the extremities. It is noticeable that *precisely this portion of the spectrum is composed of rays, which, while they more powerfully than any others affect the*

---

[1] Mosely: Notes by a Naturalist on H. M. S. Challenger, 1892, p. 512.

[2] C. A. Young: Spectrum of the Fire-fly. *Amer. Naturalist*, Vol. III, 1870, p. 615.

*organs of vision, produce hardly any thermal or actinic effect. In other words, very little of the energy expended in the flash of the fire-fly is wasted.* It is quite different with our artificial methods of illumination. In the case of an ordinary gaslight the best experiments show that not more than one or two per cent of the radiant energy consists of *visible rays*, the rest is either invisible heat or actinism ; that is to say, over ninety-eight per cent of the gas is wasted in producing rays that do not help in making objects visible."

Of Professor Langley and Mr. Very's more recent and well-known paper "On the Cheapest Form of Light,"[1] most of you are doubtless aware. As their observations are the most accurate extant on the physical properties of animal light, it will not be out of place to reproduce here at length the essential points of their conclusions, as well as some of their instructive statements on the concepts of radiant energy, which underly their experimental inquiries.

"We recall," says Professor Langley, "that in all industrial methods of producing light, there is involved an enormous waste, greatest in sources of low temperature like the candle, lamp, or even gas illumination where, as I have already shown, it ordinarily exceeds ninety-nine parts in the one hundred ; and least in sources of high temperature like the incandescent light and electric arc, where yet it is still immense and amounts, even under the most favorable conditions, to very much the larger part" (p. 97).

"It is now universally admitted that wherever there is light, there has been expenditure of heat in the production of radiation existing in and as the luminosity itself, since both are but forms of the same energy; but this visible radiant heat which is inevitably necessary is not to be considered as waste. The waste comes from the present necessity of expending a great deal of heat in invisible forms before reaching even the slightest visible result, while each increase of the light represents not only the small amount of heat directly concerned in the making of the light itself, but a new indirect expenditure in the production of invisible calorific rays. Our eyes recognize heat mainly as it is conveyed in certain rapid ethereal vibrations associated with high temperatures without passing through the intermediate low ones; so that if the vocal production of a short atmospheric vibration were subject to analogous conditions, a high note could never be produced until we had passed through the whole gamut, from the discontinuous sounds below the lowest bass, up successively through every lower note of the scale till the desired alto was reached.

---

[1] S. P. Langley and F. W. Very : On the Cheapest Form of Light, from Studies at the Allegheny Observatory with Plates III, IV, and V. *The American Journal of Science*, Third Series, Vol. XL, No. 236, August, 1890.

"There are certain phenomena long investigated, yet little understood, and grouped under the general name of 'phosphorescent,' which form an apparent exception to this rule, especially where nature employs them in the living organism, for it seems very difficult to believe that the light of a fire-fly, for instance, is accompanied by a temperature of 2000° or more Fahr., which is what we should have to produce to gain it by our usual processes. That it is, however, not necessarily impossible, we may infer from the fact that we can by a known physical process produce a still more brilliant light without sensible heat, where we are yet sure that the temperature exceeds this. No sensible heat accompanies the fire-fly's light any more than need accompany that of the Geissler tube; but this might be the case in either instance, even though heat were there, owing to its minute quantity, which seems to defy direct investigation. It is usually *assumed* with apparent reason, that the insect's light is produced without the invisible heat that accompanies our ordinary processes, and this view is strengthened by study of the fire-fly's spectrum, which has been frequently observed to diminish more rapidly toward the red than that of ordinary flames. Nevertheless this, though a highly probable and reasonable assumption, remains assumption rather than proof, until we can measure with a sufficiently delicate apparatus, the heat which accompanies the light, and learn not only its quantity, but what is more important, its quality" (pp. 98, 99).

Under "Photometric Observations," the authors continue:

"The first impression in viewing the light of the *Pyrophorus noctilucus* through a spectroscope is that it consists essentially of a broad band in the green and yellow, while with precaution we see this extending into and beyond the borders of the blue and orange, but not very greatly farther, and these have been taken by previous observers as its absolute limits. No one appears to have experimentally and distinctly answered the question, "Would the light not extend farther were it bright enough to be seen?" nor has it been proved as clearly as might be desired that the result depends on the quality rather than the quantity of the light, or given conclusive evidence that if the light of the insect were as bright as that of the sun, it would not extend equally far on either side of the spectrum.

"It is impossible to increase the intrinsic brilliancy by any optical device, but if it be impossible to make the light of the insect as bright as that of the sun, it is, on the other hand, quite possible to make the light of the sun no brighter than that of the insect, and this would appear to be the first step in obtaining a definite proof that the apparently narrow limits of the insect's spectrum are due to the intrinsic quality of the light, and not to its feeble intensity. The only conclusive method of determining this would appear to be to balance the light from the insect with that of a definite portion of sunlight by any ordinary photometric device; and having taken this sunlight as nearly equal as possible to that of the insect, though certainly not greater, to let this determined quantity fall on the slit of a spectroscope at the same time with the light from the insect, two spectra being formed one over the other in the same field and at the same time" (pp. 103, 104).

After detailing a number of experiments, the authors state that "when spectra are formed from two *equal* lights, one from the sun, the other from the insect, the latter's spectrum terminates both at an upper and a lower limit, at which the solar light is still conspicuous. The conclusion follows that the insect spectrum is lacking in rays of red luminosity, and presumably in the infra-red rays, usually of relatively great heat, or that it seems probable that we have here *light without heat*, other than that heat which the luminosity itself comprises and which is but another name for the same energy" (p. 108).

Under "Thermal Observations" the authors proceed: "To give an idea of the amount of heat at our disposition for experiment, and of the actual minuteness of the radiation which proceeds from even the most luminous tropical insect, we may say that if that rate of radiation from a lamp-black surface 1 square cm. in area, which represents the amount of heat necessary to raise 1 gram of water to 1° centigrade, in 1 minute (*i.e.* one small calorie), be taken as unity, then the luminous radiation of the fire-fly's heat, per square cm., of exposed luminous surface, as we have found, is about 0.0004 calorie in 10 seconds, and the total luminous radiation from the most powerfully illuminating light spot of the insect (the abdominal one) will not exceed 0.00007 calorie in the same time. But a small portion of this could fall upon the bolometer, and that which actually reached it during the time (10 seconds) required for each observation was sufficient only to affect an ordinary mercurial thermometer having a bulb 1 cm. in diameter by rather less than 0.00000023, or by less than 1/400000 of one degree centigrade" (pp. 108, 109).

"Resuming, then, what we have said, we repeat that nature produces this cheapest light at about one four-hundredth part of the cost of the energy which is expended in the candle-flame, and at but an insignificant fraction of the cost of the electric light or the most economic light which has yet been devised; and that finally there seems to be no reason why we are forbidden to hope that we may yet discover a method (since such a one certainly exists and is in use on a small scale) of obtaining an enormously greater result than we now do from our present ordinary means for producing light" (p. 112).

The light emitted by the living organism differs very much in color in different animals, and even in the same animal at different periods; *green* has been noticed in the glow-worm, fire-flies, some brittle-stars, centipedes, and annelids; *blue* is seen in the Italian fire-fly; *blue and light-green* are the predominant colors exhibited by marine animals; the beautiful Girdle of Venus, some species of Salpa, and Cleodora appear *red;* Pavonaria and other gorgonids are *lilac;* and one hemiptera, Fulgora, is said to emit a *purple* light. One very remarkable

Appendicularia showed in one individual first *red*, then *blue*, and finally *green*.[1] This remarkable property seems to be possessed by other tunicates, for Huxley[2] states in his well-known paper on Pyrosoma, quoting Péron, that Pyrosoma exhibited movements of alternate contraction and dilatation at regular intervals; and that each contraction was accompanied by the development of a luminosity, which, when at its brightest, was *red*, but in dying away passed through shades of *orange*, *green*, and *blue*. Newport[3] also noticed a change in the color of light emitted by the glow-worm at the end of the season from that at the beginning. I have learned in the study of several species of fire-flies, in the neighborhood of Woods Holl laboratory, to distinguish them at a distance by the color of their light, which, though slight, is still quite characteristic of the species.

The difference in color, when exhibited by different organisms, is probably due to some slight chemical differences in the light-giving substance. It may be supposed that under the influence of oxygen, the molecules of the given photogenic substance are set in vibration, the rate of vibration depending on and being characteristic of the particular species. And in those cases where a series of colors are displayed in succession by the one and the same organism, it may be supposed to be due to either of two causes: (1) the same photogenic substance is agitated with different degrees of frequencies at different periods in the life of the organism, or (2) a series of photogenic substances are produced, each one of the series representing a stage in the chemical metamorphosis of the substance. Without some definite chemical knowledge on the nature of such photogenic substances, however, it is useless to make any conjecture at present.

Nor is it easy to offer any plausible explanation as to the use of such light to the organism, which will apply with equal force to all cases. We may say this much, however, that if heat incidentally produced at first as a result of some necessary chemical changes in the body may be utilized in the course of the race history of an organism (as among birds which use heat evolved by the metabolism of their tissue for the process of incubation), it is equally conceivable that light incidentally produced as the result of a necessary combustive process of life may eventually be utilized in the race history of some species, and thus that which is an end in one organism may become the means to a remoter end in another organism. The mere fact that in some animals the light is of no apparent use to them is no reason to doubt that it may be of some use to others, in which the production of light becomes the end and purpose of some definite structure, and is even brought in connection with the mechanism of the will.

---

[1] The above is taken from W. E. Hoyle's article Phosphorescence, in the *Encyclopædia Brittanica*, Vol. XVIII, 1885.

[2] Huxley: On the Anatomy and Development of Pyrosoma. *Phil. Trans.*, 1859.

[3] Newport: On the Natural History of Glow-worms. *Proc. Lin. Soc.*, Vol. I, 1857.

While the production of light may be regarded as belonging to the same ultimate cause as that of heat, the proximate cause of the luminosity in the animal kingdom may be due to a variety of secondary circumstances.

Thus (1) an organism may appear brilliant in the dark, owing to the presence of luminous bacteria in the tissue.[1] In such a case, the luminosity of the organism may be considered as a pathological phenomenon.

In another instance (2) the organism may appear luminous also on account of the luminous bacteria which live in a symbiotic fashion in the tissue of the organism, but this cannot be called a disease, as the animal suffers no bad consequence, and may even be benefited by it.[2]

In still another case (3) transparent pelagic organisms like some crustacea may appear phosphorescent from containing in their stomachs phosphorescent food, which shines through the body of the organism. In a case like this their excrement is also phosphorescent.[3]

---

[1] See Giard: Sur l'infection phosphoresc. des Talitres et autres crustacées. *Compt. Rend.*, Sept. 23, 1889, p. 503. Peter Schmidt: On the Luminosity of Midges (*Chironomus*). *Zool. Jahrb. Abth. f. Syst. Geog. und Biologie*, Bd. VIII, Heft I, 1894. *Ann. and Mag of Nat. Hist.*, Vol. XV, 1895 (translated by Austen).

[2] R. Dubois: Sur le rôle de la symbiose chez certains animaux marins lumineux [Pelagia et Pholas]. *Compt. Rend.*, Tome CVII, 1888, p. 502.

[3] H. N. Moseley: Notes of a Naturalist, p. 498.

In the truly phosphorescent organism the luminosity is due to the metabolism of the definite tissue-cells, and the subsequent oxidation of the metabolic product, which results in the emission of light.

There can be no doubt that the majority of luminous organisms belong to this type. In some, certain cells of the body acquire the light-producing property at a certain stage of development ; in others, the organisms are luminous from the beginning of their life history. Thus Alexander Agassiz[1] observes "that the phosphorescence is equally brilliant in the egg of Ctenophoræ as in the adults, even in stages in which the masses of segmentation can still be counted. The whole embryonic mass becomes brilliantly phosphorescent when the least shock is given to the jar in which the eggs are kept."

Dubois[2] also states that in *Lampyris noctiluca* the ova taken from the ovaries and carefully washed after removal were still luminous, the development of the light being in direct relation with the degree of intraovarian development of the ova. The photogenic power in such an egg, as in many luminous protozoa, is exercised without the aid of trachea, nerves, or special anatomical elements, showing that while these elements may facilitate and even enhance for the time being the effect of luminosity, they are not to be considered thereby essential to the process of light production.

Phosphorescence is best seen in the ordinary fire-fly. If you examine the luminous cell of the common fire-fly (*Photuris pennsylvanica*), you will find it filled with peculiar yellowish-white granules, the whole cell reminding one of some actively secreting gland. These granules, by combining with oxygen brought in through the trachea and tracheal "capillaries," which closely invest the cells from all sides, give out light. It is a process of combustion which, instead of giving out heat, gives out light. These granules are the products of metabolism, the result of "secretion" process, due to the decomposition of the living substance of the cell; but instead of being thrown out of the body, like some other products of secretion, they are consumed *in situ* by combining with oxygen brought in from without.

---

[1] A. Agassiz : Embryology of the Ctenophoræ. *Mem. Amer. Acad. of Arts and Sciences*, Vol. X, No. IV. Cambridge, Mass., 1874.

[2] R. Dubois : De la fonction photogénique dans les œufs du lampyre. *Bull. Soc. Zoöl. France*, XII, 1887, p. 137.

The fact that the granules themselves are dead is shown by taking the luminous organ from the organism and crushing it on the slide, thus depriving it of all traces of vitality; yet the light continues to come out, in fact it becomes more luminous the greater the exposure to air.

The mode by which each luminous cell is aërated by the tracheal "capillaries" is of considerable interest. The "capillaries" are the ultimate branches of the respiratory apparatus, and start from the ultimate branches of the tracheal tube, somewhat in a similar manner as the tentacles do from the body of a hydra. If one imagines these "capillaries" are spread around the photogenic cell in the same manner as the hydra spreads its tentacles around an organism much larger than itself, which it has captured for food, he may get a fair idea of the relation of the aërating apparatus to the light-producing cell.

The size of the luminous cell being comparatively large, more than one bunch of hydriform "capillaries" is found distributed over the surface of each luminous cell. The substance of the "capillaries" seems to have a remarkable affinity for oxygen, and it is, no doubt, through this mechanism that the oxygen of the inspired air is quickly separated, and just as quickly applied for the combustion of the photogenic material in the periphery of the cell.

As to the chemical nature of this material little is known; but it is a secretion of fatty nature, which oxidizes readily in alkaline media. Phosphorus has nothing to do with the phenomenon.

The animal has control of the production of light through its respiratory mechanism, not directly upon the luminous cell, although nerves may have indirect influence upon the general metabolism of the cell. When more oxygen is sent with the air, the illumination is greater; when the air is withheld, there is less light, or even a complete darkness, just as the dull red coal may be ignited so as to emit a white light by a steady application of fresh air upon it by the action of the bellows.

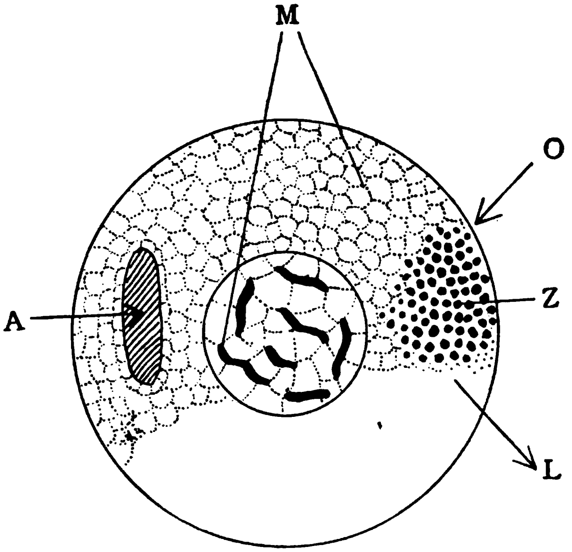
The fact that the illumination of the cell is due to the action of oxygen may be shown in a simple way by putting the slide on which the luminous organ has been crushed, and the photogenic material spread out, into a jar containing carbon dioxide. The light disappears almost instantly; but if the same slide be placed in a jar containing oxygen, or simply exposed to air, the light comes back, and lasts as long as the luminous material, a certain amount of moisture, and other necessary conditions are present.

This process can be repeated several times, showing conclusively that the light-giving material itself is quite independent of cell-life, although it owes its existence primarily to the life activity of the cell as a whole.

The luminous phenomenon, wherever it occurs, is apparently carried on by essentially the same process throughout the animal kingdom. In air-breathing organisms, such as the fire-fly, the product of cell metabolism is oxidized *in situ* by the oxygen of the inspired air. In some marine organisms the secretion is often thrown out in the form of liquid from the gland to the surrounding medium, and the oxidation is accomplished by the oxygen dissolved in the sea water. In luminous Salpa the photogenic granules formed in the blood-corpuscles are oxidized by the oxygen dissolved in the blood plasma.

Perhaps I can summarize the preceding, and make my point more intelligible by the help of a diagram.

We have seen that the essential bases for the luminous phenomena of the living organism consist (1) in the production of a certain chemical substance in the cell, which recalls to our mind the well-known series of phenomena in the process of secretion; and (2) the oxidation of this substance by the oxygen brought in from without, and thus making the cell a new center of disturbance to the surrounding ether.



| LIVING CONSTITUENTS OF THE CELL. | NON-LIVING CONSTITUENTS OF THE CELL. |
|---|---|
| *M Protoplasm* { (a) Cytoplasm.<br>(b) Chromosome. | { (a) *Food* (*A*).<br>(b) *Photogenic granules* (*Z*). |
| *O Oxygen*, acting on the photogenic granules. | |
| *L Light*, emanating from the cell, as the result of oxidation. | |

The food-substance, which I represent, for the sake of convenience, by the block (*A*) in the accompanying diagram, enters the cell boundary, and becomes eventually assimilated into the protoplasm (*M*); the complex living substance, or protoplasm, becomes disintegrated into a number of granules (*Z*) which are no longer "living," and which may be regarded as refuse of life. The definite chemical molecules which constitute these granules combine with oxygen (*O*), and the molecular agitation, which accompanies the chemical process of combustion, sets the surrounding ether into a state of vibration (*L*), which has a powerful luminous effect on us, but little or no thermal effect.

Thus, the life of the luminous cell, like that of any other cell, begins with the physical and ends with the physical. We know the beginning (*A*); and we also know the termination (*L*). The unknown territory in the middle (*M*) is what we call the protoplasm, or the matter in the living state.

There is one suggestion of some importance which flows from this.

That most living matter needs oxygen for the maintenance of life is a well-established fact, but in what precise manner this oxygen is ultimately used in the organism, is a question to which we can give hardly any satisfactory answer at present.

In the luminous cell of the fire-fly, in which the mechanism of oxygenation is carried to its highest perfection, it is comparatively easy to trace the path of oxygen, and how it is used in the living cell. *The oxygen here simply combines with the dead substance prepared in the cell.* The value of oxygen to the luminous function of the organism lies in its ability to combine with the dead substance produced by the activity of the living. Is it possible that the relation of oxygen to life in general is of a similar nature? Does the value of oxygen to life lie primarily in its ability to combine with the dead substances, which exist side by side with the living, in all cells? The hæmoglobin is a complex iron compound found in the red blood-corpuscle. Oxygen loosely combines with this compound and forms oxyhæmoglobin. The oxygen in this new compound is given up in the tissue through which the blood circulates, and the compound returns back to the original hæmoglobin, which, coming back to the respiratory organ, combines again with the free oxygen, and begins the rôle of oxygen-carrier again. Here, again, the substance in the cell which combines with the oxygen is not the living substance, but the dead material formed by the activity of the cell. Professor Loeb suggests that it is possible that the relation of oxygen to life may be of this nature in all cases.

It may be that in the luminous cell of the fire-fly the method of oxidation is carried out with a highly specialized apparatus, and the result of oxidation of the dead material conveyed in such a form as to affect the most delicate of our sense-organs, and that the relation of oxygen to the life of the cell in general is thus revealed here with simplicity and clearness unparalleled in the whole series of vital activities. At any rate, this aspect of the question may not be devoid of interest when taken in connection with the fundamental problem of the relation of oxygen to living substance, or respiration, in which, some have even maintained, lies hidden the whole mystery of life.